COCHRAN, SEAN M., M.S. Task Performance is Inversely Related to Spatial External Focus Target Removal (2019).
Directed by Dr. Louisa D. Raisbeck. 43 pp.

External focus (EF) of attention (focusing on the effects of movement on the environment and/or on an external target) has shown to enhance performance in motor tasks. These findings are consistent in the literature, however, there is limited literature for attentional focus in the virtual environment (VE). Target characteristics and target occlusion are known to change in VE, positively effecting performance. This study examined the effects that EF and target characteristic changes have on jump performance in a controlled virtual environment. Sixty participants performed a series of single leg jumps with or without EF instructions, in and out of a VE. Significant differences both RW and VE for performance were observed for baseline Significant differences between groups for the training conditions of the target removal were not dependent on time between removal and movement execution. Lastly, both groups had better performance at retention than at baseline. This study showed that an EF target supplements the stimulus-response link by adding to environmental characteristics affecting event-file retrieval, and performance.

TASK PERFORMANCE IS INVERSELY RELATED TO SPATIAL EXTERNAL

FOCUS TARGET REMOVAL

by

Sean M. Cochran

A Thesis Submitted to
the Faculty of The Graduate School at
The University of North Carolina at Greensboro
in Partial Fulfillment
of the Requirements for the Degree
Master of Science

Greensboro
2019

Approved by

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APPROVAL PAGE

This thesis written by Sean M. Cochran has been approved by the following committee of the Faculty of The Graduate School at The University of North Carolina at Greensboro.

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CHAPTER I

INTRODUCTION

Motor learning can be measured through observation of improved motor behavior or performance (Newell & Slifkin, 1996). Performance is influenced by many factors and is highly variable, however through learning performance can improve (Keele, 1968). Learning is typically represented through the retention of a skill after a period of skill acquisition. Depending on the motor task or skill will depend on how long a retention period is required to show learning benefits (Farr, 1986; Mumford, Weeks, Harding, & Fleishman, 1987). Although learning has been widely represented in motor behavior studies, the idea of directing attentional focus and examining retention is relatively new. Wulf, HoB & Prinz (1998) suggested that attention should be directed to specific information sources or to objects that were readily available in the environment. Attentional focus was defined into external (directs attention to the effects of their movements on the environment) and internal focus, (directing attention to their own actions). Along with increases in performance, learning can be enhanced through external focus by shortening the initial stages of skill acquisition (Wulf, McNevin, & Shea, 2001). Literature exists to show that verbal, visual and auditory factors enhance learning and performance when administered using attentional focus instructional cues (Benz, Winkelman, Porter, & Nimphius, 2016; Cutton & Landin, 2007; Ho & Spence, 2005; Raisbeck & Diekfuss, 2016; Shea & Wulf, 1999; Wulf, Shea, & Lewthwaite, 2010).

In addition to external focus of attention, changes to target characteristics have an influence on motor performance. Increasing the distance of an external target, have been shown to result in improving performance in jumping tasks (Westphal & Porter, 2013; Porter, Anton, &Wu, 2012; McNevin, Shea, & Wulf, 2003). Bennett and Barnes (2006) and Schlesinger, Porter, and Russell (2013) found that performance differences between a fully visualized target and an occluded target did not vary greatly showing that vision is not a determining factor in performance improvements. Contributing to this idea of target occlusion, Ahissar and Hochstein (2000) examined a phenomenon of between types of practice and whether it produces generalized or specific learning. Changing characteristics of the target involved with practice, making the task easier or harder, made the task more generalized or specified regarding learning. This suggests that changing target characteristics to make the task more difficult, target occlusion or removal, enhances performance related to that specific task. With the literature being well supported demonstrating the use of external targets to augment external focus, it is predicted that creating an environment manipulating the way the target is presented may show similar results of enhancements and learning.

A primary explanation for the benefits of external focus of attention can be explained by the constrained action hypothesis (Wulf, McNevin, & Shea, 2001). The hypothesis states that when performers use an internal focus of attention, their automatic control processes may be constrained. Conversely, when performers use an external focus of attention their motor system can naturally self-organize. This natural self-organization of an external focus of attention allows for a change in the motor outcome resulting in automatized and efficient movements (Kal, van der Kamp, & Houdijk, 2013; Vidal, Wu, Nakajima, & Becker, 2018).

Although the benefits of using an external focus are profound across many domains (Kal, van der Kamp, & Houdijk, 2013; Shea & Wulf, 1999; Vidal, Wu, Nakajima, & Becker, 2018; Wulf, Lauterbach, & Toole, 1999; Wulf, Mcconnel, Gärtner, & Schwarz, 2002; Wulf, Shea, & Lewthwaite, 2010), a current gap within the literature is examining how target characteristic changes or target removal effect learning. Manipulation of environment and target characteristics require a modality that allows us to change these details in real-time, therefore using a virtual environment would allow for creation, immersion, and adaptation to be achieved. Virtual reality is computer generated, mimicking real world environments, and has gained popularity in training motor skills. Virtual reality provides a safe space for individuals to learn motor tasks, in addition to manipulating movement in a space that creates repetitive motion for practice (Hoffmann, Filippeschi, Ruffaldi, & Bardy, 2014; Lohse, Shirzad, Verster, Hodges, & Van der Loos, 2013)

The purpose of this study is to further examine the effects of external focus and target characteristics changes have on jump performance in a controlled virtual environment. This research is important because of the potential applicability that a simple target characteristic change has and the potential implications for motor performance. Based on the previous literature the following hypotheses were made:

Hypothesis 1: There will be a change in performance when performing a single leg jump task in the real world compared to the virtual environment prior to training.

Hypothesis 2: The external focus group will exhibit longer jump distances when training in the virtual environment relative to the control group.

Hypothesis 3: Higher retention performance will be observed in the external focus group when compared to baseline and internal retention performance.

CHAPTER II

REVIEW OF THE LITERATURE

Overview

This literature review will evaluate attentional focus specific to instructional cueing and how different instructional cues can result in superior motor performance and learning. In addition, this literature review will focus on attentional focus instruction in a virtual environment specific to target duration, virtual reality and performance. The first part of this literature review covers relevant literature examining attentional focus cueing and how it is instructed. Lastly, hypothesized explanations for differences in performance due to attentional cueing and changes to target characteristics will be discussed.

Motor Learning and Instruction

Training is imperative when it comes to the acquisition, development, and retention of a motor skill. Therefore, the discovery of effective and efficient methods during training is important for researchers and practitioners, so the best practices can be disseminated and implemented. Wulf, HoB, & Prinz (1998) noted various aspects of the training had been examined such as organization of practice, frequency of feedback, and physical guidance (Magill & Hall, 1990; Schmidt, 1991; Winstein, Pohl, & Lewthwaite, 1994). However, it wasn't until 1997 that instructions specific to performance and learning were investigated (Wulf & Weigelt, 1997). Previously, individuals received instructions through verbal instructions or through observation of body movements.

Wulf, Hob and Prinz (1998) combined this instruction methodology with the idea that attenuating to one's process of performance produces performance decrements by decreasing the automaticity of a learned movement (Baumeister, 1984). Wulf, Hob, and Prinz (1998) sought to investigate an optimal instruction strategy in order to enhance performance, leading to different forms of attentional focus.

Instructional Cue Delivery

Verbal instruction is one of the most common forms of instruction (McKenzie, Clark, & McKenzie, 1984; Benz, Winkelman, Porter, & Nimphius, 2016). Auditory and visual cues have also been suggested to be important to performance due to these cues being detected by multiple sensory apparatuses in the body, stimulating different processing centers in the brain (Ho & Spence, 2005). Typically, when instructional cues are provided, individuals are directed to specific parts of their body. These cues eventually become less as an individual's gains experience and knowledge of their activity. Once the cues lessen, we know that individuals are typically entering a more automatic stage of their learning and performance (Rink, 2006). Based on the expertise literature, we understand that when experts have been asked to refocus on specific body parts that their performance was negatively affected (Krampe & Ericsson, 1996). This research paved way for understanding the attentional focus literature that shows motor performance can improve based on instructions (Wulf, HoB, & Prinz, 1998; Wulf, Lauterbach, & Toole, 1999; Wulf, McNevin, & Shea, 2001; Porter, Anton, & Wu, 2012). A change in instruction of how and where to focus can provide significant improvements in the performance of motor tasks (Wulf, Hob, & Prinz; 1998; Gokeler et al., 2015; Benz, Winkelman, Porter, & Nimphius, 2016; Ouvrard, Groslambert, & Grappe, 2018).

External v. Internal Focus

Research has demonstrated the way instruction is structured can influence performance effects. The attentional focus paradigm and theory explains how to optimize training and coaching through instructional cues. The division and definition of attentional focus into internal and external focus was previously stated. The current literature suggest that using an external focus of attention will result in superior performance and learning compared to primarily using an internal focus of attention (Wulf, HoB, & Prinz, 1998; Wulf, Lauterbach, & Toole, 1999; Wulf, McConnel, Gartner, & Schwarz, 2002; McNevin, Shea, & Wulf, 2003). Wulf, HoB, and Prinz, (1998) investigated the attentional focus phenomenon in two different experiments. In the first experiment, participants were separated into an internal or external focus condition. For the internal focus condition, participants were told to focus on their feet, in contrast the external group focused on the wheels of the ski-simulator. The results of this study demonstrated the external focus group (focusing on the wheels) led to higher learning and retention performance. The second experiment examining balance on a stabilometer instructed participants to focus on their feet (internal focus) or keeping the two markers placed on the board level (external focus). The study also showed superior learning and retention effects for external focus compared to internal focus. This study also revealed that this instructional cueing could be transferred to different tasks since it was transferred from ski-simulator to a balance board.

In contrast, findings by Castaneda and Gray (2007) found external focus to be less helpful for lower-skilled performers executing a baseball swing. This could be due to the nature of the task itself and the time constraints to complete the task that focusing on external targets are not an option. It could also be due to the additional task demands of a motor task that is a dual-task. We understand from the dual task literature that the findings are not consistent with studies that are only looking at one task. For example, Beilock, Carr, MacMahon & Starkes (2002) examined attentional focus using a slalom soccer task. Right foot dominant individuals were asked to dribble with their right or left foot while receiving a skill focus task or a dual-task condition. Skill focused instructions were to state whether the inside or outside of their foot was touching the ball when the auditory cued played. The dual-task condition consisted of random words being said with a target word of "thorn". Participants in this condition then stated when the target word was said, while still performing the slalom task. Results revealed thatindividuals using their non-dominant foot performed better under a "skill focused" direction (Beilock, Carr, MacMahon, & Starkes, 2002). Reviewing this study, there are no description of what instructions were provided to the participants other than to focus on their feet and to state whether the inside or outside of their foot was touching the ball at the presentation of an extraneous tone. Although the verbal instructions draw their attention to the foot, it is still confounded with the external tone that they were required to attend to. Without a manipulation check, it is difficult to determine where the focus was. Based on the literature related to attentional focus, ideally it is better to not include the dual task literature due to the differences in instructions, however, there have a been a number of studies that have examined the benefits from external focus and how they transfer to other motor tasks; stabilometer (Shea & Wulf, 1999), volleyball (Wulf, Mcconnel, Gärtner, & Schwarz, 2002) and golf (Wulf, Lauterbach, & Toole, 1999). Overall, these studies show that an external focus of attention enhanced performance. To explain the difference between an external and internal focus of attention, a number of theories (constrained action hypothesis, dechunking of proceduralized skills or skill focused performance) have been proposed.

Attentional Focus Theories

The constrained action hypothesis has been used to explain the benefits observed from using an external focus of attention (Wulf, McNevin, & Shea, 2001). The hypothesis suggests that using an internal focus of attention constrains the automatic control processes of the body. Whereas, an external focus of attention allows the motor system to naturally self-organize. This natural self-organization was examined through the frequency of postural adjustments. Newell and Slifkin (1996) first discussed the idea of higher frequency responses as an indication of a more effective integration of the active degrees of freedom for the motor task being performed, as well as a greater cooperation and blending of reflexive and voluntary control mechanisms. This blend of reflexive and voluntary control mechanisms could be used to explain the evidence supporting an external focus producing a more automated response.

To further understand the constrained action hypothesis, Wulf, Shea, and Ji-Hoon (2001) examined the frequency and amplitude of postural adjustments during a balancing task. Participants came into the lab for multiple practice days and each chose an internal or external instruction. After two days of practice they were asked which attentional focus they thought was more effective and were asked to use that form of attentional focus for the remainder of the practices. The researchers observed that participants exposed to external focus performance, even if a participant started with internal and switched to external or remained with an external focus the entire time, showed higher performance and retention than those who stayed with internal. They also observed that those who focused on their feet (internal) showed larger amplitudes and lower frequencies of postural adjustments than their fellow participants given an instruction to focus on the markers on the board (external). These findings lead Wulf and colleagues to believe that external focus of attention brings a more controlled or automated reflexive response during postural control than internal focus of attention.

Dual-Task Performance

Since external focus instruction provided the body with a more automated performance response and relies on more of reflexive control systems, an additional task should not decrease performance. This idea is another way that researchers have tried to explain this constrained action hypothesis through dual-task performance. Dual-task performance is assessed while two concurrent tasks are being performed. The first task is to be studied for changes in performance (primary) and the second task drawing most of the performer's attention (secondary). One of the first studies to investigate this methodology was Wright and Kemp (1992). Their results showed that attenuating to a secondary task (reaction time) while performing a simple motor task, such as walking, has effects on the performance of the primary task (walking with a walker). Since having to attenuate to a secondary task while performing a primary task effects performance, adding attentional focus instruction can help bridge the gap and offer learning effects as well. Using this dual-task theoretical framework, Wulf, McNevin, and Shea (2001), examined the automaticity of an external focus of attention using a stabilometer for a simple reaction time task. Results showed that response times were lower in all conditions after practice, but the external focus group showed lower numbers for performance and retention. It was determined if external focus of attention causes a more natural, self-organizing control processing, then reaction times would be lower in the external focus group compared to the internal focus group.

Amount of Attentional Cueing

Based on previous literature, there is strong support that an external focus of attention is superior for learning and performance. Ziegler (1987) first examined the effectiveness of verbal instruction with regards to skill acquisition and performance of tennis. Beginning tennis players were asked to verbally self-cue the processes of performing a return forehand or backhand. For example, when the tennis ball struck the court before coming back up towards the player they were instructed to say “bounce”. When the ball contacted the racquet, they were instructed to say “hit”. Results showed that players using the self-cueing method had higher rates of successful backhand or forehand returns compared to baseline. Comparing these results to previous literature regarding instructional cueing and combining it with what is now known of external and internal focus of attention, leaves the question as to the right amount of cueing.

Previous research has shown that cueing needs to be minimal, including features of the task that needs to be performed, and appropriate to the skill level of the performer (Masser, 1993; Landin, Cutton, & Macdonald, 2007; Rink, 2006). Raisbeck and Diekfuss (2017) discovered that performers of a simulated shooting task performed better at immediate retention when receiving one cue than those that received three cues no matter the form of instruction. These findings expanded the current literature by discovering that people receiving the external focus cues had higher performance numbers as well as lower reported workloads at delayed retention. This suggests that performers can retain the skills for longer periods of time with minimal instruction received.

Jumping Tasks and Attentional Focus

Since the literature suggests performance can be improved through minimal, skill specific, external attentional focus cueing the next step is to apply it to different performance measures. According to Porter et al. (2010) standing long jump performance can be improved through external focus of attention. Participants were divided into two groups, internal and external. The internal group received the instruction "When you are attempting to jump as far as possible, I want you to focus your attention on extending your knees as rapidly as possible." The external group received the instruction "When you are attempting to jump as far as possible, I want you to focus your attention on jumping as far past the start line as possible." Results revealed that the average jump distance of the external group was significantly larger than those in the internal group. An increase in performance aligns with external focus of attention increasing performance, but the cause of this increase is unclear.

First trying to explain this reflexive and increased performance, Vance et al. (2004) hypothesized that these enhancements occur at the neuromuscular level. They tested at the neuromuscular level with electromyography (EMG) measuring at the active muscle. The researchers first had participants perform bicep curls while focusing on their arms (internal) or the bar itself (external). They found that bicep curls were performed at a faster rate, but lower EMG activity with the external focus group when compared to the internal focus group. Vance and colleagues then performed a different experiment where the procedure was the same except the timing of the bicep curl was controlled with a metronome. Again, they found the external group to have lower EMG activity even though range of motion was similar to the first experiment. So, an increase of performance does not seem to be because of elevated neuronal activity at the muscle level.

Even though the muscle does not have high neuronal activity, it is plausible to think that this enhancement in performance could be caused by increases in peak force generated. Wu, Porter, and Brown (2012) investigated if the increase in jump performance with external focus of attention instruction could be caused by a higher peak force generated. Participants were divided into internal and external groups. Wu, Porter, and Brown noticed similar differences in performance as in previous literature, such as increased performance with external focus, but saw no differences in peak force. With no evidence of peak force being the cause of enhanced jump performance, yet previous research showing a decrease in EMG activity due to external focus of attention, this adds supporting evidence to the constrained action hypothesis where external foci produces more efficient and automated movement.

Target Distance

Performance for different motor skills are improved through external instructional cues given. Targets the external instructional cues are directed towards can also affect performance. McNevin, Shea, and Wulf (2003) reviewed the current literature at the time and discovered a relationship between a task's target distance in relation to increases in performance. For example, in a study examining external focus and golf performance, immediate results were observed since the external cue was to focus on the golf club head (Wulf, Lauterbach, & Toole, 1999). Conversely, a study examining external focus instruction and a balance task on a stabilometer found that external focus of attention instruction did increase performance in keeping the board stable, but it was only apparent during retention after days of practice (Wulf, Hob, & Prinz.,1998). McNevin, Shea, and Wulf noticed that the external target attended to was right at the edge of the performer's feet.

Noticing a difference in target distances between these studies, McNevin, Shea, and Wulf (2003) investigated whether distance mattered in motor performance and learning. Following the protocol from Wulf, Bell and Hardy (2009) and Mckay and Wulf (2012) conducted a similar studies designed to investigate if distance is a concern. Results showed that although immediate performance results were not detectable when the target was farther away, superior learning through mediation of the automatic control processes was observed. With the discovery that learning is enhanced by increasing target distance, applying this concept to different performance measures to show greater performance over time is the next step.

Porter, Anton, and Wu (2012), hypothesized that focusing on an external target that is farther away allows for more control of degrees of freedom in a popular agility test, the standing long jump. Participants were divided into a control, external-near, or an external-far group. The control received no instruction whereas the external-near group received external focus instruction on a target that was close to their feet and the external-far group received external focus instruction on a target that was three meters away from them. Results showed that the further the external target was, the better the performance. These results further supported the constrained action hypothesis demonstrating that external cues placed further away from the individual continues to provide added performance benefits, although it is still unknow how far an external target needs to be to still show performance benefits.

Visual Target Duration

Another way to change the characteristics of a target is how long does the target need to be in the view of the individual. Schlesinger, Porter, and Russell (2013) asked participants to complete a manual tracking task on a computer. Participants completed a pre-test spatial memory task, and then a practice trial, keeping a cursor in a circular target. During acquisition, the circular target path was randomized and a grey rectangle appeared in the center of the screen to occlude the path of the circle, and focus of attention cues were provided. Instructions for internal focus was "focus on how your hand moves", external-near group was to "focus on how the mouse moves", and the external-far group was "focus on how the cursor moves". Similar to previous literature, the external-far group outperformed the external-near and internal groups in terms of a decrease in tracking errors. The performance did not vary greatly between the target being fully shown or occluded concluding that vision, or visual feedback, is not as important in focus of attention cueing.

Virtual Reality and Effects on Human Performance

If visual feedback is not as important as it previously was suggested, removing the target after receiving instruction could provide some more insight into the phenomenon. One method to investigate this would be examining attentional focus and target occlusion in a virtual environment using jumping as the motor task. Virtual reality has become more user friendly in the recent years and provides an opportunity to have a controlled environment. In addition, it can expose participants to different sensory experiences such as visual, auditory, and proprioception, in the simulation of real-world environment (Hoffman et al., 2014). The impact that virtual reality can have on both expanding research techniques and in rehabilitation is profound due to expanding from a minimized controlled laboratory environments into a more realistic, expansive environment that offers real world experiences. Recent research has shown that virtual reality enhances real world performance. Hoffman et al. (2014) suggested that virtual reality is beneficial for learning optimal pace strategy for energy conservation in rowing performance. It is well documented that walking, obstacle crossing, and rowing (dynamic tasks) show increases in performance in virtual reality. LoJacono et al. (in press), found that practicing and adopting better strategies for obstacle crossing in a virtual environment transfers to better performance of obstacle crossing in the real world. although virtual reality benefits are well documented, it is still unclear what drives the performance enhancement. One possible explanation is the novelty of the virtual environment to the performer increases engagement. Loshe, Shirzad, Verster, Hodges, and Van der Loos (2013) investigated different levels of interaction and engagement of patients in a walking rehabilitation setting. Loshe et al., 2013 found that the higher the level of interaction, for example racing an artificial character compared to walking at a normal pace with no competitor, leads to better performance at motor rehabilitation tasks. Zimmerli, Jacky, Lünenburger, Riener, and Bolliger (2013) examined the current state of virtual reality in the rehabilitation setting and found increased motor engagement through video game techniques such as feedback and goal achievement. These studies investigated virtual reality characteristics and their effects on participants level of participation. Both studies suggest that virtual reality allows rehabilitation patients to perform movements that they would typically do in physical therapy in a more stimulating environment. In addition, evidence suggested that virtual reality may enhance skill acquisition due to the repetitive nature, specificity of a task, and real-time feedback options that are available (Wulf, 2010). Virtual reality offers anovel mediated learning environment to enhance performance even if the performer has experience with the motion (Patel, Bailenson, Hack-Jung, Diankov, & Bajcsy, 2008).

In sum, virtual reality can be used to create environments tailored to an individuals specific need, or standardized across a population (Fung, 2017). A virtual space provides safer spaces to practice movements. When we consider this in combination with what we understand about attentional focus, it would be a step further to bridging a gap in the current literature that can address safe an effective practice environments with the additive benefits of performance and learning

Current Gaps

An empirical question for the attentional focus literature is ‘what is the optimal external focus target?’. Manipulation of an external focus target has been studied (Bell & Hardy, 2009; McKay & Wulf, 2012; Porter, Anton, & Wu, 2012; Schlesinger, Porter, & Russell, 2013), however limited research exists discussing target removal before the performer executes a motor task. Examining this phenomenon in combination with virtual reality will allow manipulation of the target in real time helping to explain whether a visual target needs to be present before the movement is initiated.

CHAPTER III

OUTLINE OF PROCEDURES

Participants

Sixty healthy young adults (22.51 ± 2.86) were recruited from the University of North Carolina at Greensboro (UNCG) and the surrounding area. All participants had normal or corrected to normal vision, no cognitive impairment, no current musculoskeletal injuries, and the ability to jump forward on one leg unaided. Participants completed an informed consent previously approved by the institutional research board.

Instrumentation

Qualisys motion capture cameras (Gothenburg, Sweden) were used to capture kinematic data and overall jump distance. Unity 3D (Copenhagen, Denmark) in combination with HTC VIVE system (Bellevue, Washington) was used to create and implement the immersive virtual environment. A total of six Qualisys reflective markers were used on each foot. These markers were adhered to the shoe using a matte colored tape with no reflective properties. Markers were placed on the front tip of the shoe, the lateral side of the first and fifth metatarsals, below the lateral and medial side of the malleolus, and on the back of the calcaneus.

Virtual Reality

The virtual environment and Qualisys capture space was approximately 3.5 meters squared. The virtual environment consisted of a green landscape with a pink circle to mark where participants would begin the task. An arrow on the pink circle showed participants the direction that the external target (an orange cone) would appear. This allows participants to orient themselves to be facing the direction of the cone. The cone appeared in the distance (5 meters) after the wireless remote, connected to the VIVE system, was clicked.

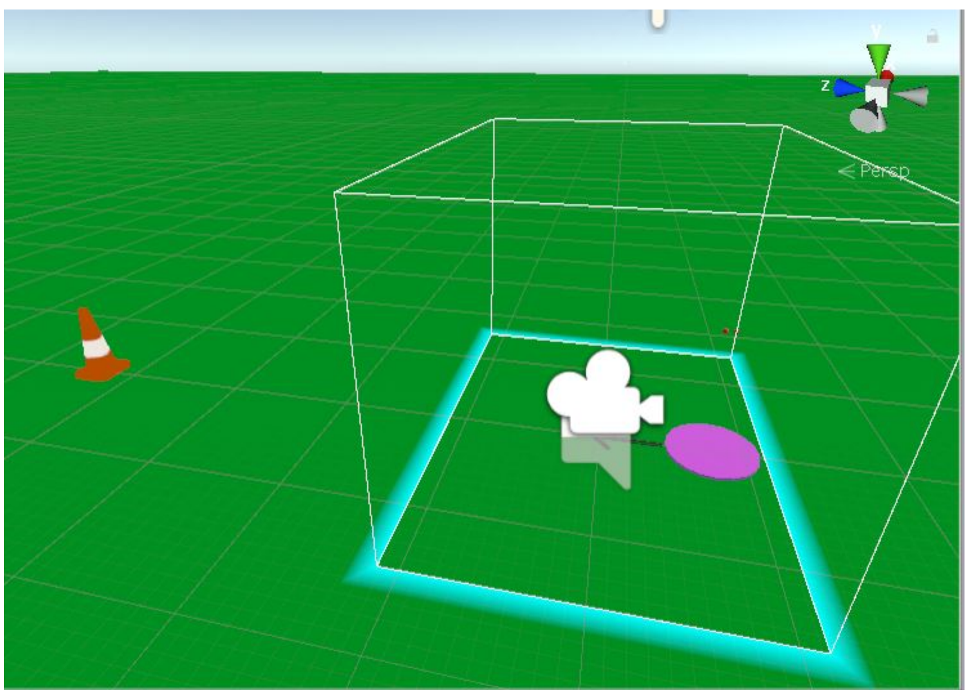

Figure 1. Virtual Environment

Depending on the condition, the cone will disappear after 5 seconds. The cues “ready” and “jump” were provided to instruct the participant when to jump after 5 or 10 seconds after the disappearance of the cone. When the participant completed their jump, red spheres were used to mark the position in the virtual space. The foot marker changed from red to green in order to alert the performer which leg to use in the trial for the single-leg jump.

Procedure

Prior to testing, participants provided a medical history, consented to participate, and completed a 5-minute warm-up on a stationary bike. Reflective markers were then placed before participants entered into the VIVE system.

Participants completed a baseline of six jumps on the non-dominant limb in the real and virtual environment and were measured for jump distance. These baseline jumps consisted of no external target and were told to jump as far as they can. For testing trials, jumps were divided into three even blocks with a total of 9 jumps performed again on the non-dominant limb in the virtual environment. One-minute rest periods were inserted between training blocks to reduce chances of fatigue. For the control group, no cone was provided, and the instruction was to jump as far as you can. For the external focus group, conditions were randomized by the amount of time between the cone's removal and movement execution. These trials were randomized by the performer jumping immediately, five seconds, or ten seconds after the cone's removal. Each trial condition was performed once in each training block. External focus cueing was provided at the beginning of each training block. The external focus cue stated “Jump as far as you can, while you are jumping I want you to focus on jumping as close to the cone as possible.” For each participant the VIVE system randomized the condition for the participant to perform. Qualisys collected jump distances as the participant left from the circle and landed on the tested foot. The initiation of a jump was recognized by Qualisys when the markers were 5 centimeters from the ground. The threshold of 5 centimeters was administered due to the height of the shoes and height of the markers when the participant is level on the ground. Each trial ended as the foot stopped forward motion and passed below the 5-centimeter threshold.

After a 2-minute period, participants performed an immediate retention test. Testing consisted of jumping on the nondominant leg in the virtual environment capture space with no instruction received and no cone present. Then again in the real-world environment.

Data Collection and Analysis

The data from motion capture was exported to Excel, rendering jump distances for each trial. Jump distances for each trial were then averaged depending on time and condition. Jump distances were determined from the starting circle when the markers were raised past the 5-centimeter threshold to the back of the heel once forward motion ceased. SPSS was used to run all statistical tests. Alpha level was set a priori to 0.05. To address hypothesis 1, a 2 x 2 (group x environment) ANOVA was run for jump distances in real-world and virtual baseline across conditions. To address hypothesis 2, a 2 x 4 (group x manipulation) ANOVA was run for jump distances in external focus group and controls across virtual baseline and virtual training jump conditions. Follow-up paired t-tests were used to determine differences between manipulation points. To address hypothesis 3, multiple 2 x 2 (group x condition) ANOVAs were run comparing virtual baseline to virtual retention, virtual retention to real world retention, and real world baseline to real world retention.

CHAPTER IV

RESULTS

Table 1. Participant Demographics by Group. Demographics [mean(SD)] for Participants including Sex, Age, Mass, and Height

Group	N	Male	Female	Age (yrs)	Height (m)
Control	30	9	21	22.53(2.96)	1.67(.094)
EF	30	13	17	22.48(2.80)	1.71(.085)

Tables 2. Summary of Results for (RW) Real World, (VR) Virtual Environment, (VT) Virtual Target Removal

Groups	RW Baseline	VR Baseline	VT 0s Delay	VT 5s Delay	VT 10s Delay	VR Retention	RW Retention
Control	1.38 (.322)	1.23 (.385)	1.30 (.424)	1.32 (.398)	1.25 (.465)	1.29 (.425)	1.53 (.350)
EF	1.44 (.303)	1.28 (.350)	1.47 (.430)	1.48 (.412)	1.48 (.396)	1.40 (.395)	1.60 (.324)

Hypothesis 1: There will be a change in performance when performing a single leg jump task in the real world compared to the virtual environment prior to training.

A 2 x 2 (group x baseline) ANOVA was conducted to determine condition differences across both real world and virtual baselines. No significant interaction between conditions at both baselines was found ($F(1,58)=.038$, $p>.05$). A main effect for environment was found ($F(1,58)=52.52$, $p<.05$) showing a decrement in jump performance when transferring from real world to the virtual environment at baseline.

Hypothesis 2: The external focus group will exhibit longer jump distances when training in the virtual environment relative to the control group.

A 2 x 4 (group x manipulation) ANOVA was calculated comparing the jump distances of participants at four different times: virtual baseline, immediate target removal, 5 second delay after target removal, and 10 second delay after target removal. A significant time by condition interaction was found ($F(3,174)= 7.11$, $p<.001$). A follow up independent t-test was conducted to determine no group differences at baseline ($t(58)=-.398$, $p>.05$). Next, a series of paired t-test were then used to determine whether significant differences existed between baselines and manipulations trials relative to each group. Paired t-tests for controls showed no differences between the baseline when compared to immediate ($p=.53$), 5 second delay ($p=.38$), and 10 second delay ($p=.84$). For the external focus group, all manipulation conditions were trending toward significant increase in performance with immediate ($p=.10$), 5 second delay ($p=.06$), and 10 second delay ($p=10$).

Hypothesis 3: Higher retention performance will be observed in the external focus group when compared to baseline and internal retention performance.

A 2 x 2 (group x condition) ANOVA was conducted to examine virtual baseline to virtual retention. No significant interaction was found between the conditions at each time point ($F(1,58)=2.41$, $p>.05$). A main effect for condition was found ($F(1,58)=22.07$, $p<.001$). Next, a 2 x2 (group x condition) ANOVA was conducted to examine the difference between virtual and real world retention. No significant interaction was found between conditions at virtual and real world retention ($F(1,58)=.883$, $p>.05$). A main effect for condition was revealed ($F(1, 58)=82.69$, $p<.001$). To examine real world baseline to real world retention a 2 x 2 (group x condition) ANOVA was conducted. No significant interaction was found between conditions at real world baseline and retention ($F(1,58)=.046$, $p>.05$). A main effect for condition was discovered ($F(1,58)=73.61$, $p<.05$). All tests suggest a learning effect is not dependent on whether or not external focus instructions were provided.

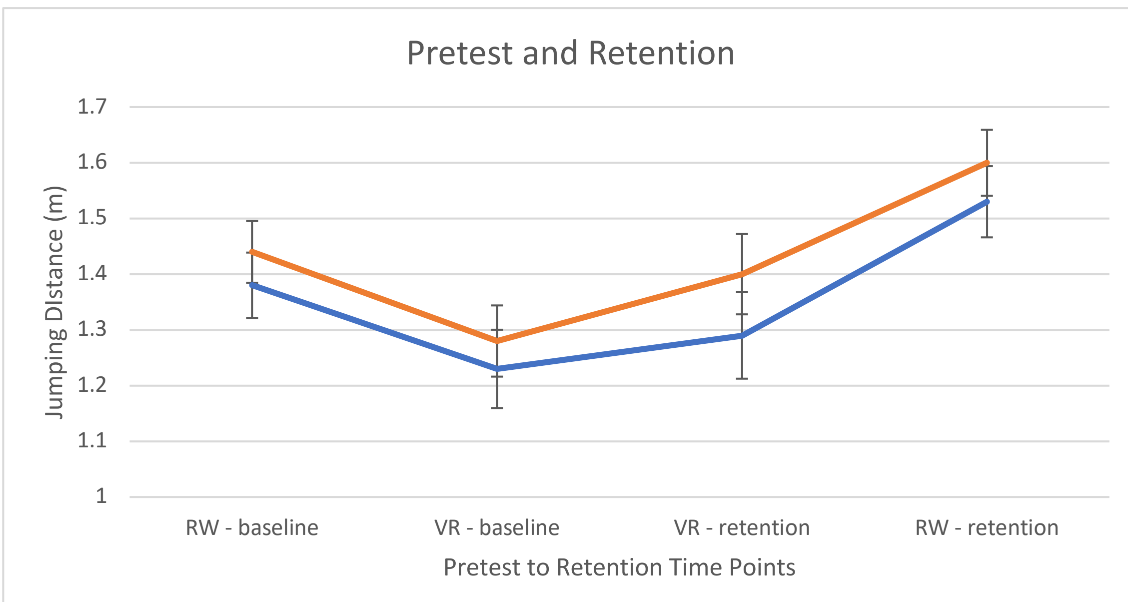

Figure 2. Pretest to Retention of Real World and Virtual Reality in Meters. Averages Shown with Standard Error Bars.

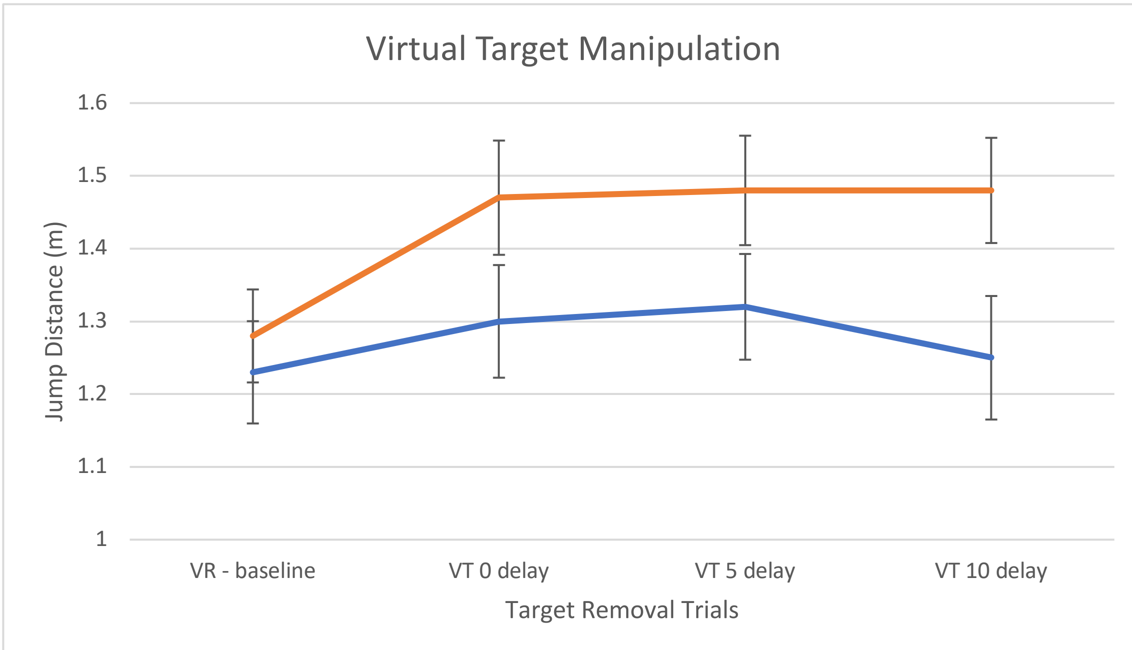

Figure 3. The Relationship between Target Removal and Movement Execution from Baseline. Averages Shown with Standard Error Bars.

CHAPTER V

DISCUSSION

This study examined whether external focus target removal had an effect towards motor performance and to the retention of these performance effects. Retained performance was shown after training in virtual. Performance enhancements were revealed during the virtual training trials with target removal before movement execution when an external focus was adopted. However, retention testing showed no differences between those who received external focus instructions and those to received no instructions.

For the first hypothesis, we proposed that there would be a change in jump performance once a participant transfers from the real world to the virtual environment. Significant differences were not observed between conditions at baseline which is to be expected due to no instruction or cone being present for those trials. However, a significant decline in jump performance was observed for both groups when performing the task in the virtual environment compared to the real world.

Although the beneficial effects of virtual reality are well documented (Bailenson et al., 2008; Hoffmann, Filippeschi, Ruffaldi, & Bardy, 2014; Howard, 2017; Keshner & Fung, 2017; Lohse, Shirzad, Verster, Hodges, & Van der Loos, 2013; LoJacono C.T. et al., 2018; Zimmerli, Jacky, Lünenburger, Riener, & Bolliger, 2013), evidence also exists to performance decrements in the initial trials when switching from real world to virtual reality (Lewis & Griffin, 1998). Decrements could be due to the virtual having different environment characteristics and performance feedback measures. This finding shows that performers experience a decrement in performance that lasts throughout their training in virtual reality. Implications from this finding show that even though virtual reality may be a modality to simulate a real world environment, real world performance may not be observed. This suggests that real world performance and virtual performance may not be directly comparable and that measuring or testing someone's motor skill set in virtual may not be a holistic representation of their motor ability. This has rehabilitation implications showing that if we continually monitor someone at a task in virtual without checking to see their progression of motor ability at the same task in a real environment, we may not have an accurate representation of their trained motor performance in the real world. One strategy in order to begin bridging this gap between real world and virtual performance is addressed with our second hypothesis.

For the second hypothesis, we proposed the external focus group would exhibit longer jump distances when training in the virtual environment relative to controls. This hypothesis was somewhat supported, as we observed a trend towards a significant increase in jump performance for the external focus group compared to controls across the virtual training trials. This increase in the external focus group performance was not dependent on increasing the time between target removal and movement execution, suggesting a target present throughout the entire motion is not necessary.

As we have observed previously, full visualization of the target is not necessary to see performance enhancements with an external focus of attention (Ahissar & Hochstein, 2000; Schlesinger, Porter, & Russell, 2013). This study adds to the literature supporting this phenomenon and furthers it by showing the target does not have to return to the performer's visual field in order to enhance performance. Conclusions drawn by Schlesinger et al. (2013) are supported by our findings suggesting there is a potential dissociation between cognitive focus, which does not require visual input, and visual focus. We propose that performers encode the distal position of the cone, supplementing their stimulus-response event file. With this encoding and the importance of distal environmental characteristics when creating a stored event file (Hommel, 2009; Prinz, 1992), the added stimulus of an external target supplements the stimulus-response link to allow this continued consistency in performance.

Not only were external focus enhancements trending towards becoming significantly different from controls across training, they were trending towards becoming significantly higher than their respective virtual baseline. Since we observed a significant drop in performance at the virtual baseline trials, external focus of attention directed towards a target can increase performance measures in virtual reality closer in alignment to real world performance levels. Further investigation of this phenomenon across different motor tasks in virtual reality are necessary to see if this effect is transferable to other performance measures.

Feedback is important in the early stages of learning as long as the performer does not become dependent (Winstein, Pohl, & Lewthwaite, 1994). In the real world baseline, performers had full visualization of their limbs, trunk, and the distance they had jumped from the start line. Once they entered the virtual environment, those feedback processes were removed. This could also explain the decrease in performance transitioning from real world to virtual reality. After entering virtual, the external group received a possible feedback measure with their external focus of attention. They were instructed to “jump as close to the cone as possible”. Even though the target was not present throughout the execution of the movement, participants encoding this position may have been receiving distance feedback. Thus, enhancing performance.

For the third hypothesis, we proposed higher retention performance in the external focus group compared to controls. We did not observe any significant differences between groups for the different retention intervals, yet each group improved significantly across all trials. Observing this trend, and with previous research, it could be suggested that virtual reality serves as a plausible training modality in relation to improving real world performance. These enhancements across groups in real world performance could be explained through cognitive transfer processes from current virtual reality technologies (Weiss, Keshner, & Levin, 2014). In order for a skill to transfer from a virtual environment to a real world environment, the virtual environment needs to provide important information to facilitate learning (Rose, Attree, Brooks, Parslow, & Penn, 2000) or require the learner to adapt to challenging demands (Bossard, Kermarrec, Buche, & Tisseau, 2008). We may have seen an increase performance at retention in both groups due to the challenging nature of our environment. With the environment, no other feedback was given other than the position of their feet (excluding the cone encoded by the external focus group). Thus, they had no visual information of limb or torso position, affecting balance, and making the single leg jumping task more challenging compared to the real world. Since they trained in an environment with no incorporated feedback, entering back into the real world brought feedback into their cognitive processes. Once these feedback measures (distance from start line, limb and torso position) returned, a spike in retention performance was observed. It is possible that training without these feedback measures, then the addition of them after training, resulted in these higher performance outcomes. The addition of a real-world training group in comparison to our virtual training group in a between subjects design would be needed to further support our claim that training in virtual is beneficial to real world motor learning. In addition, further research is needed to observe how long the effects revealed during retention last.

Limitations

This study did not include a group with an external focus instruction and a fully visualized target to compare to the target removal group. As such, it is difficult to ascertain differences between an external target being removed and a visualized target throughout the entire motor performance. Additionally, safety measures included in the software of the UNITY 3D system may have affected jump distances in the virtual components of the study. Safety measures consisted of virtual mesh barrier letting the performers know when they were close to the pre-determined boundaries of the virtual environment. Performers were shown the wall beforehand and instructed that if they interacted with this barrier, they were safe, and it was possible to jump through the barrier. For more experienced or athletic performers, they tended to interact with the virtual protective barrier more frequently than most. We believe this to be based on commentary from participants mentioning they had seen or were alarmed by the mesh barrier appearing. More experienced jumpers may have felt more comfortable jumping at further distances without the appearance of this barrier. Lastly, due to the study being conducted in a communal lab space there were markings on the floor of the real-world environment that were unable to be moved. Participants may have developed an external attentional focus during the baseline or retention trials not dependent on if they were in the control or external focus group. These markings may not only have served as an external target but also as a means for knowledge of results feedback. We believe this may have affected real world testing trials by participants commentary on trying to reach certain marks on the floor. The limitations of the virtual barrier and the markings in the real world could also help to explain the disparity between the trials where the performers transitioned from the real world to virtual reality.

This study sought to investigate the visual properties of target removal of externally focused attention and its effects on single leg jump performance. Our findings support the use of virtual reality as a training modality due to the challenging nature of completing the same task without certain feedback processes. Researchers and clinicians alike need to be cautious not to suggest a participant's virtual performance is equivalent to their possible real world performance. Additionally, our findings support the claim that external focus of attention, whether a target is present or not, can help increase virtual performance by encoding the position of the target. Continued investigation of this target removal performance phenomenon is necessary due to real world implications towards administration of external focus of attention training. Adding a comparison of this target removal strategy to previous external focus protocol would help us to gain a better understanding of the effects towards the implications of target removal. Additionally, understanding the influence the visual information system plays into the development of performance during external focus of attention instruction could lead to adaptations of external focus protocol.

Future directions would be to continue investigating this external focus target removal by comparing the effects against a fully visualized target. Additionally, the external focus effects towards jump performance in virtual reality needs to be compared to other motor tasks and performance measures in order to understand its transferability and applicability to all performance protocol in virtual reality. Lastly, extended retention times need to be examined in order to gain an understanding as to when the observed practice effects diminish.

REFERENCES

Ahissar, M., & Hochstein, S. (2000). The spread of attention and learning in feature search: Effects of target distribution and task difficulty. Vision Research, 40(10), 1349–1364. https://doi.org/10.1016/S0042-6989(00)00002-X

Bailenson, J., Patel, K., Nielsen, A., Bajscy, R., Jung, S.-H., & Kurillo, G. (2008a). The Effect of Interactivity on Learning Physical Actions in Virtual Reality. Media Psychology, 11(3), 354–376.

Bailenson, J., Patel, K., Nielsen, A., Bajscy, R., Jung, S.-H., & Kurillo, G. (2008b). The Effect of Interactivity on Learning Physical Actions in Virtual Reality. Media Psychology, 11(3), 354–376. https://doi.org/10.1080/15213260802285214

Baumeister, R. F. (1984). Choking under pressure: Self-consciousness and paradoxical effects of incentives on skillful performance. Journal of Personality and Social Psychology, 46(3), 610–620. https://doi.org/10.1037/0022-3514.46.3.610

Beilock, S. L., Carr, T. H., MacMahon, C., & Starkes, J. L. (n.d.). When Paying Attention Becomes Counterproductive: Impact of Divided Versus Skill-Focused Attention on Novice and Experienced Performance of Sensorimotor Skills. ATTENTION AND PERFORMANCE, 12.

Bell, J. J., & Hardy, J. (2009). Effects of Attentional Focus on Skilled Performance in Golf. Journal of Applied Sport Psychology, 21(2), 163–177

Bennett, S. J., & Barnes, G. R. (2006). Combined smooth and saccadic ocular pursuit during the transient occlusion of a moving visual object. Experimental Brain Research; Heidelberg, 168(3), 313–321. http://dx.doi.org/10.1007/s00221-005-0101-3

Benz, A., Winkelman, N., Porter, J., & Nimphius, S. (2016). Coaching instructions and cues for enhancing sprint performance. Strength & Conditioning Journal, 38(1), 1–11.

Bossard, C., Kermarrec, G., Buche, C., & Tisseau, J. (2008). Transfer of learning in virtual environments: A new challenge? Virtual Reality, 12(3), 151–161. https://doi.org/10.1007/s10055-008-0093-y

Castaneda, B., & Gray, R. (2007). Effects of focus of attention on baseball batting performance in players of differing skill levels. Journal of Sport and Exercise Psychology, 29(1), 60–77.

Cutton, D. M., & Landin, D. (2007). The Effects of Self-Talk and Augmented Feedback on Learning the Tennis Forehand. Journal of Applied Sport Psychology, 19(3), 288–303. https://doi.org/10.1080/10413200701328664

Farr, M. J. (1986). The long-term retention of knowledge and skills: A cognitive and instructional perspective. Institute for Defense Analyses Alexandria VA.

Fung, J. (2017). Gait and balance training using virtual reality is more effective for improving gait and balance ability after stroke than conventional training without virtual reality [commentary]. Journal of Physiotherapy, 63(2), 114. https://doi.org/10.1016/j.jphys.2017.02.010

Gokeler, A., Benjaminse, A., Welling, W., Alferink, M., Eppinga, P., & Otten, B. (2015). The effects of attentional focus on jump performance and knee joint kinematics in patients after ACL reconstruction. Physical Therapy in Sport, 16(2), 114–120. https://doi.org/10.1016/j.ptsp.2014.06.002

Ho, C., & Spence, C. (2005). Assessing the effectiveness of various auditory cues in capturing a driver's visual attention. Journal of Experimental Psychology: Applied, 11(3), 157.

Hoffmann, C. P., Filippeschi, A., Ruffaldi, E., & Bardy, B. G. (2014). Energy management using virtual reality improves 2000-m rowing performance. Journal of Sports Sciences, 32(6), 501–509. https://doi.org/10.1080/02640414.2013.835435

Hommel, B. (2009). Action control according to TEC (theory of event coding). Psychological Research Psychologische Forschung, 73(4), 512–526. https://doi.org/10.1007/s00426-009-0234-2

Howard, M. C. (2017). A meta-analysis and systematic literature review of virtual reality rehabilitation programs. Computers in Human Behavior, 70, 317–327. https://doi.org/10.1016/j.chb.2017.01.013

Kal, E. C., van der Kamp, J., & Houdijk, H. (2013). External attentional focus enhances movement automatization: A comprehensive test of the constrained action hypothesis. Human Movement Science, 32(4), 527–539. https://doi.org/10.1016/j.humov.2013.04.001

Keele, S. W. (1968). Movement control in skilled motor performance. Psychological Bulletin, 70(6, Pt.1), 387–403. https://doi.org/10.1037/h0026739

Keller, M., Lauber, B., Gehring, D., Leukel, C., & Taube, W. (2014). Jump performance and augmented feedback: Immediate benefits and long-term training effects. Human Movement Science, 36, 177–189. https://doi.org/10.1016/j.humov.2014.04.007

Keshner, E. A., & Fung, J. (2017). The quest to apply VR technology to rehabilitation: Tribulations and treasures. Journal of Vestibular Research: Equilibrium & Orientation, 27(1), 1–5. https://doi.org/10.3233/VES-170610

Krampe, R. T., & Ericsson, K. A. (1996). Maintaining excellence: Deliberate practice and elite performance in young and older pianists. Journal of Experimental Psychology: General, 125(4), 331.

Lohse, K., Shirzad, N., Verster, A., Hodges, N., & Van der Loos, H. M. (2013). Video games and rehabilitation: Using design principles to enhance engagement in physical therapy. Journal of Neurologic Physical Therapy, 37(4), 166–175.

LoJacono C.T., Raisbeck L.D., Ross S.E., Rhea C.K., MacPherson R.P., & Kuznetsov N.A. (2018). Obstacle crossing in a virtual environment transfers to a real environment. Journal of Motor Learning and Development, 6(2), 234–249. https://doi.org/10.1123/jmld.2017-0019

Magill, R. A., & Hall, K. G. (1990). A review of the contextual interference effect in motor skill acquisition. Human Movement Science, 9(3–5), 241–289.

Masser, L. S. (1993). Critical Cues Help First-Grade Students' Achievement in Handstands and Forward Rolls. JOURNAL OF TEACHING IN PHYSICAL EDUCATION, 12(3), 301.

McKay, B., & Wulf, G. (2012). A distal external focus enhances novice dart throwing performance. International Journal of Sport and Exercise Psychology, 10(2), 149–156. https://doi.org/10.1080/1612197X.2012.682356

McKenzie, T. L., Clark, E. K., & McKenzie, R. (1984). Instructional strategies: Influence on teacher and student behavior. Journal of Teaching in Physical Education, 3(2), 20–28.

McNevin, N. H., Shea, C. H., & Wulf, G. (2003). Increasing the distance of an external focus of attention enhances learning. Psychological Research, 67(1), 22–29.

Mumford, M. D., Weeks, J. L., Harding, F. D., & Fleishman, E. A. (1987). Measuring Occupational Difficulty: A Construct Validation Against Training Criteria. Journal of Applied Psychology, 72(4), 578–587. https://doi.org/10.1037/0021-9010.72.4.578

Newell, K. M., & Slifkin, A. B. (1996). Motor control and human skill: A multidisciplinary perspective. Champaign, IL: Human Kinetics.

Ouvrard, T., Groslambert, A., & Grappe, F. (2018). CHAPITRE 3: Déterminants psychophysiologiques de la performance cycliste lors d'un championnat national du contre-la-montre. Étude Des Mécanismes Psychophysiologiques Impliqués Dans La Réalisation d'une Performance Cycliste de Haut-Niveau, 85.

Porter, J. M., Anton, P. M., & Wu, W. F. W. (2012). Increasing the Distance of an External Focus of Attention Enhances Standing Long Jump Performance: Journal of Strength and Conditioning Research, 26(9), 2389–2393. https://doi.org/10.1519/JSC.0b013e31823f275c

Porter, J. M., Ostrowski, E. J., Nolan, R. P., & Wu, W. F. W. (2010). Standing Long-Jump Performance is Enhanced When Using an External Focus of Attention. Journal of Strength and Conditioning Research, 24(7), 1746–1750.

Prinz, W. (1992). Why don't we perceive our brain states? European Journal of Cognitive Psychology, 4(1), 1–20. https://doi.org/10.1080/09541449208406240

Raisbeck, L. D., & Diekfuss, J. A. (2016). Verbal Cues and Attentional Focus: A Simulated Target-Shooting Experiment. Journal of Motor Learning and Development, 5(1), 148–159. https://doi.org/10.1123/jmld.2016-0017

Rink, Judith. (2006). Teaching physical education for learning (5th ed.). Boston: McGraw-Hill.

Rose, F. D., Attree, E. A., Brooks, B. M., Parslow, D. M., & Penn, P. R. (2000). Training in virtual environments: Transfer to real world tasks and equivalence to real task training. Ergonomics, 43(4), 494–511. https://doi.org/10.1080/001401300184378

Schlesinger, M., Porter, J., & Russell, R. (2013). An External Focus of Attention Enhances Manual Tracking of Occluded and Visible Targets. Frontiers in Psychology, 3. https://doi.org/10.3389/fpsyg.2012.00591

Shea, C. H., & Wulf, G. (1999). Enhancing motor learning through external-focus instructions and feedback. Human Movement Science, 18(4), 553–571. https://doi.org/10.1016/S0167-9457(99)00031-7

Vance, J., Wulf, G., Töllner, T., McNevin, N., & Mercer, J. (2004). EMG Activity as a Function of the Performer's Focus of Attention. Journal of Motor Behavior, 36(4), 450–459.

Weiss, P. L. (Tamar), Keshner, E. A., & Levin, M. F. (2014). Current and Future Trends for VR and Motor Rehabilitation. In P. L. (Tamar) Weiss, E. A. Keshner, & M. F. Levin (Eds.), Virtual Reality for Physical and Motor Rehabilitation (pp. 217–226). https://doi.org/10.1007/978-1-4939-0968-1_11

Westphal, W., & Porter, J. M. (n.d.). Increasing the Distance of an External Focus of Attention has Limited Effects on Standing Long Jump Performance. 10.

Winstein, C. J., Pohl, P. S., & Lewthwaite, R. (1994). Effects of physical guidance and knowledge of results on motor learning: Support for the guidance hypothesis. Research Quarterly for Exercise and Sport, 65(4), 316–323.

Wright, D. L., Kemp, T. L., Winstein, C. J., & Li, Y. (1992, April). The dual-task methodology and assessing the attentional demands of ambulation with walking devices. Physical Therapy, 72(4), 306-. Retrieved from General OneFile.

Wu, W. F. W., Porter, J. M., & Brown, L. E. (2012). Effect of Attentional Focus Strategies on Peak Force and Performance in the Standing Long Jump. Journal of Strength and Conditioning Research, 26(5), 1226.

Wulf, G. (2013). Attentional focus and motor learning: A review of 15 years. International Review of Sport and Exercise Psychology, 6(1), 77–104. https://doi.org/10.1080/1750984X.2012.723728

Wulf, G., Höß, M., & Prinz, W. (1998). Instructions for Motor Learning: Differential Effects of Internal Versus External Focus of Attention. Journal of Motor Behavior, 30(2), 169–179. https://doi.org/10.1080/00222899809601334

Wulf, G., Lauterbach, B., & Toole, T. (1999). Learning advantages of an external focus in golf. Research Quarterly for Exercise and Sport, 70, 120–126.

Wulf, G., McConnel, N., Gärtner, M., & Schwarz, A. (2002). Enhancing the learning of sport skills through external-focus feedback. Journal of Motor Behavior, 34(2), 171–182.

Wulf, G., McNevin, N., & Shea, C. H. (2001). The automaticity of complex motor skill learning as a function of attentional focus. Quarterly Journal of Experimental Psychology: Section A, 54(4), 1143–1154. https://doi.org/10.1080/02724980143000118

Wulf, G., Shea, C., & Lewthwaite, R. (2010). Motor skill learning and performance: A review of influential factors. Medical Education, 44(1), 75–84. https://doi.org/10.1111/j.1365-2923.2009.03421.x

Wulf, G., & Weigelt, C. (1997). Instructions about physical principles in learning a complex motor skill: To tell or not to tell…. Research Quarterly for Exercise and Sport, 68(4), 362–367.

Ziegler, S. G. (1987). Effects of stimulus cueing on the acquisition of groundstrokes by beginning tennis players. Journal of Applied Behavior Analysis, 20(4), 405–411. https://doi.org/10.1901/jaba.1987.20-405

Zimmerli, L., Jacky, M., Lünenburger, L., Riener, R., & Bolliger, M. (2013). Increasing Patient Engagement During Virtual Reality-Based Motor Rehabilitation. Archives of Physical Medicine and Rehabilitation, 94(9), 1737–1746. https://doi.org/10.1016/j.apmr.2013.01.029